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The AMERICAN JOURNAL of OPTOMETRY

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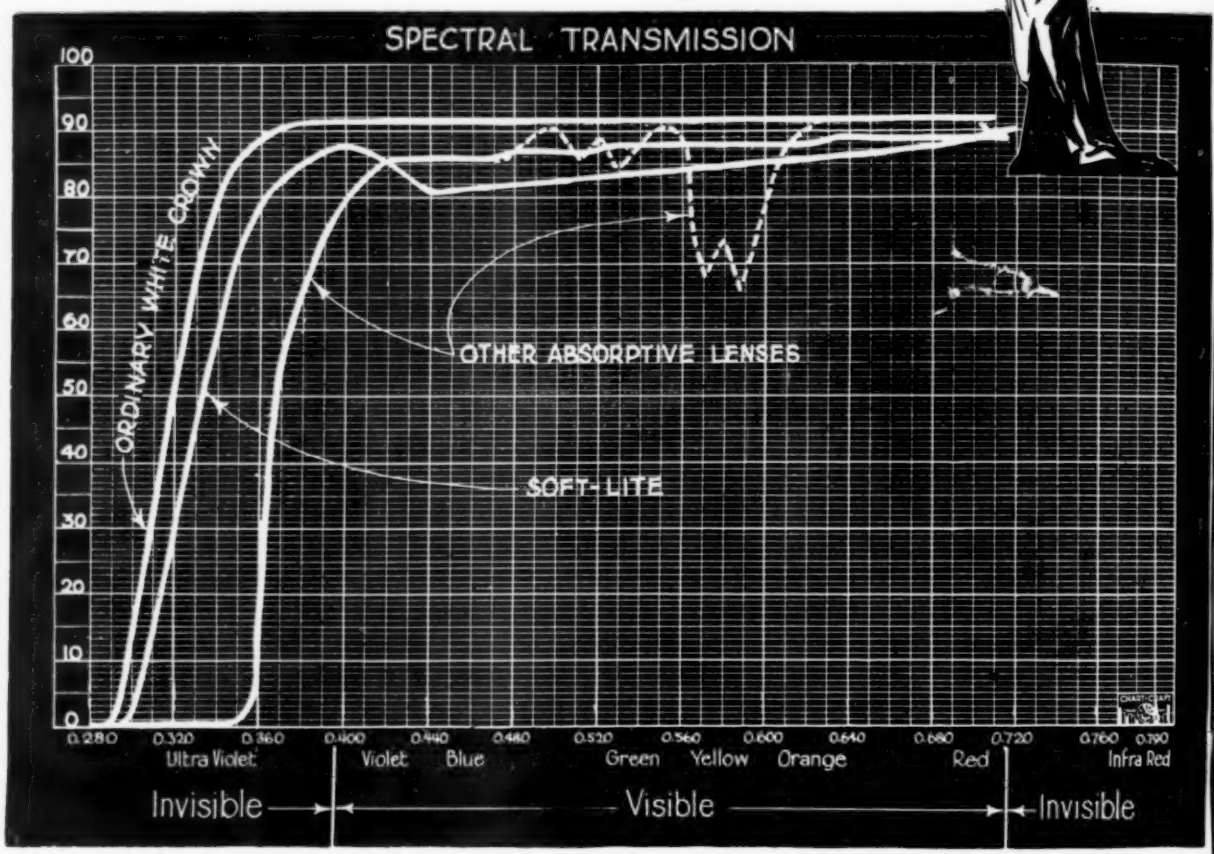

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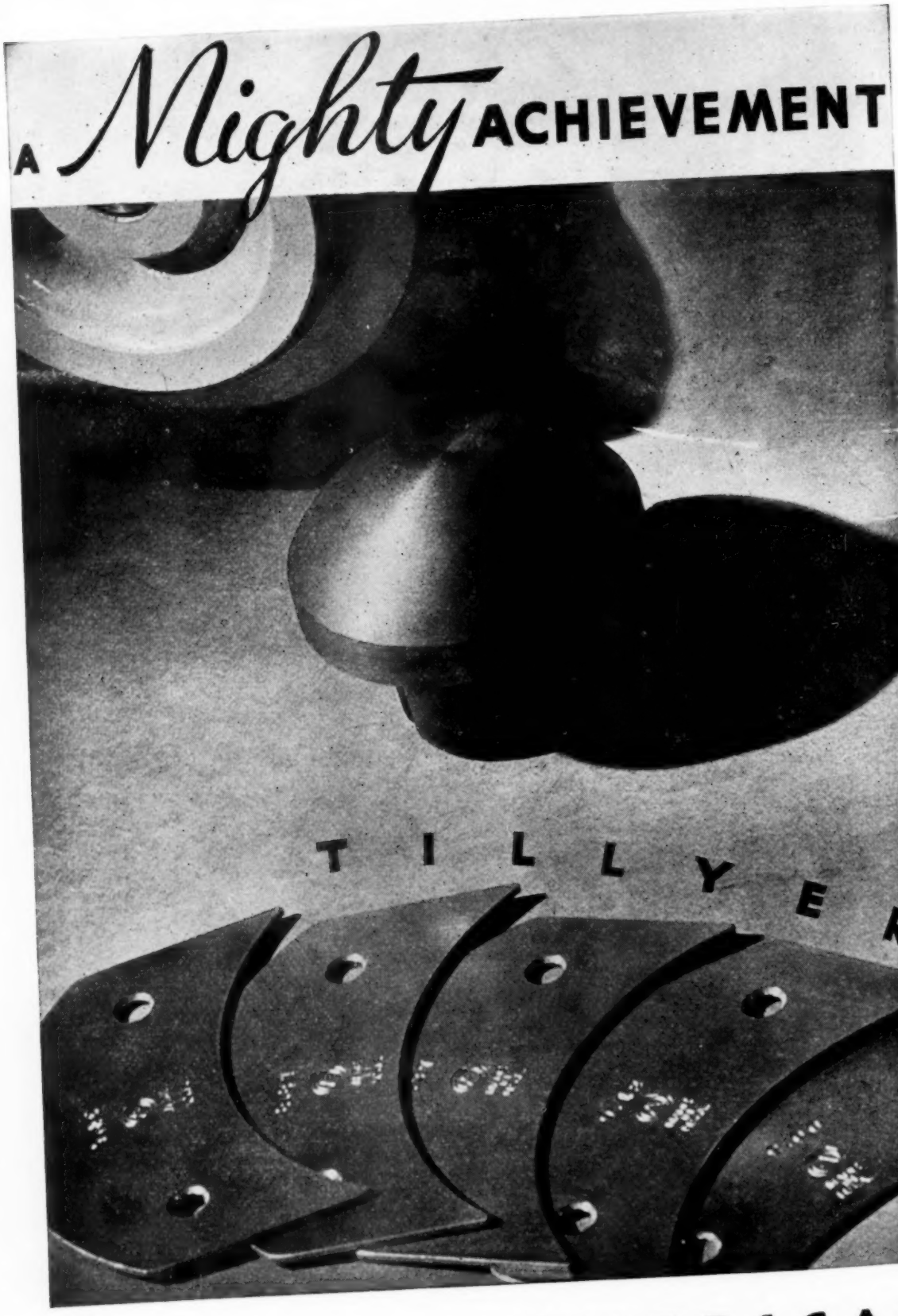
A Mighty ACHIEVEMENT
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AMERICAN JOURNAL OF OPTOMETRY

Vol. 11 SEPTEMBER, 1934 No. 9

BICHROME REFRACTION*

E. LeRoy Ryer, Opt. D., D. O. S., F. A. A. O.
and
Elmer E. Hotaling, Opt. D., D. O. S., F. A. A. O.
New York, N. Y.

Chromoptometry, duochrome refraction, bichrome refraction are synonymous terms applied to a recently developed method of measuring subjectively and monocularly the refraction of the human eye by means of two monochromatic test objects.

From these various terms we will choose Bichrome Refraction, first, because it is as descriptive as any and, secondly, because the device for applying its principles is known in this country as the Bichrome Check Test instead of the Ericiscope, as in France.

The test utilizes the chromatic aberrations of the eye but while these aberrations were discussed by Newton, Wollaston, Young and, especially, Helmholtz, we think the credit for making them available in the practice of optometry should go to Pech and Imbert of France whose original papers, respectively, "Physiologic and Clinical Value of Chromatic Aberration of the Eye" and "Chrom-optometry," opened a vast new field.

The investigation and application of radiant energy lying within the visible spectrum belong so specifically and fittingly to the optometrist that we experience keen pleasure in presenting to the American Academy of Optometry for its consideration a paper dealing with the subject based solely upon the use of two light filters, one transmitting monochromatic red light of essentially 7,100 A. U., the other monochromatic blue of essentially 4,500 A. U.

Pech and Imbert have carried the work to a point where it is clinically applicable to:

(1) The measurement, monocularly, of the static refraction of the human eye.

(2) The measurement, monocularly, of the dynamic refrac-

*An abridgement of the material presented before the American Academy of Optometry at Baltimore, December 17, 1933.

tion of the human eye.

(3) The measurement, monocularly, of variations of the ocular refraction in connection with abnormal nutritional conditions which affect the indices of refraction of the different media.

(4) The measurement, monocularly, of cases presenting such unusual conditions as aphakia and color blindness.

We have carried their work a little farther and supplemented monocular with binocular tests, taking into consideration the effect convergence seems to have upon accommodation which though extremely slight in quantity looms large in diagnostic value where it does show, usually in cases of pseudo myopia and latent hypermetropia.

We have demonstrated the possibility of making it as useful and dependable as a near point test as it is a far point test at present, provided proper filters are available.

We have demonstrated that in cases of red blindness its accuracy is lowered but that in green blindness its accuracy is enhanced.

We have demonstrated here, as we did in perimetry and campimetry, the need for preliminary tests of the color sense.

We have demonstrated the superiority of the bichrome test to other tests in cases of very young children, illiterates, mental defectives, amblyopes and other cases of subnormal visual acuity.

With what we believe to be true conservatism, we predict outstanding developments in this field and hope this introduction will stimulate the optometrist to take the lead in their development because the intrinsic worth of the test leaves no doubt that if he fail to grasp it someone less capable of doing it justice will do so.

But let no exaggeration creep in. We are not unaware of the fact that a complete subjective examination may be built upon bichrome refraction, but we think its chief value at this time lies in its unique corroborative qualities; as such it is a most simple test; it is purely subjective, cannot be made objective; as a check test it calls for no change in anyone's technique for it takes the final findings, by whatever route arrived at, and adds a refining touch exactly doubly as sensitive as any other subjective check test known today.

At what value, then, are we to rate a subjective test even though it be of double sensitivity?

As much as we might like to think otherwise, the fact remains that outside of academic laboratory discussions the final prescription for glasses is based always upon subjective findings, wherever subjective findings are available. In practice, subjective data however meager are depended upon with greater confidence than objective data however elaborate. This confidence in subjective findings is almost universal and almost universally justified.

Such a state of affairs within a practice as highly technical as

optometry cannot be a matter of chance.

There have been those in plenty who have advocated, and some who actually have practiced prescribing from objective findings; probably every neolicentiate in the practice of optometry resolves at one time or another to prescribe boldly from his objective findings but just as probably recalls that resolve as his experience recedes from schematic eye set-ups into the maelstrom of real human visual problems.

So true is this that not a single instance stands on record of anyone continuing to base prescriptions for glasses in all cases solely or primarily upon objective findings.

Such a practice, totally lacking in subjective tests, is inconceivable because even the patient ignorant of the examiner's language or the child too young to submit to routine subjective tests or the deaf mute will shake the head negatively, scowl, pull off the glasses or throw down the reading matter, if the glasses are not comfortable, thereby applying belatedly and often to the examiner's chagrin, the subjective principles which, however crude and limited they may appear, should have been applied before the prescription was determined upon finally.

None of this must be taken as the slightest disparagement of objective methods. Retinoscopy and ophthalmometry reign supreme in their respective fields. Subjective findings of the highest or the lowest order are facilitated and enhanced, always, by objective findings. We believe objective methods essential to high grade subjective work, cannot conceive an optometrist of today practicing successfully without them, but clear reasoning dictates that retinoscopy and ophthalmometry invaluable as they are as essential parts of any proper routine, are nonetheless exploratory, pathfinding preliminaries, always enhancing if carefully deduced but never superseding subjective data deduced with equal care.

If visual problems involved anatomy only, as many would fain believe, objective methods no doubt would suffice, just as they suffice now in schematic eye work; if they involved anatomy and physiology alone it is conceivable that objective methods still might suffice; but inasmuch as visual problems involve of necessity anatomy, physiology and psychology, with psychology the dominant factor, subjective methods likewise remain dominant.

Hence, accurate subjective refraction represents the highest state of the art and anything which enables the practitioner in optometry to improve subjective findings is of paramount importance.

The bichrome check test doubles the sensitivity and the precision of the present subjective tests which, of course, are polychromatic tests, the white test chart being an outstanding example.

The novelty of the test lies not in new, untried principles but rather in the correlation of a number of old, well seasoned principles which have stood the test of time. Its uniqueness lies in taking advantage of the natural chromatic aberration of the eye instead of continuing to accept it supinely as a disadvantage.

We recognize the existence of and calculate the effects of blur circles; we know that white light is broken up into various colors by the dispersive properties of prisms and lenses; we know that the eye is not achromatic; we know that colored blur circles therefore must exist; but while we grant the validity of these phenomena in their respective departments we have hesitated to correlate the various departments. Bichrome refraction does just this and in so doing creates a new subjective test almost unbelievably simple and accurate. At the same time and for the first time it places refractive measurements of the human eye upon the international standard of optical measurements, as we will proceed to show.

The refractive index of all gases, fluids and solids is based upon the sodium light of the solar spectrum. This standard is accepted universally by scientists. All lenses and prisms are calibrated accordingly. Thus a 1.00 diopter lens is a lens whose principal focus is at one meter *for yellow light;* such a lens is stronger than 1.00 diopter for green, blue or violet light and weaker than 1.00 diopter for orange or red. The sodium is the brightest area in the spectrum and in a spherical optical system not corrected for chromatic aberration, forms the circle of least diffusion. Thus, because the yellow of the ordinary forms of illumination is the brightest and least diffused the eye instinctively favors it and ignores the duller more diffused blur circles of the other colors which, with yellow, are found in sunlight and commonly used artificial illuminants. This is significant and should be kept in mind in relation to all considerations of bichrome refraction.

Hence, if by evolution and training the eye instinctively prefers clear to blurred images, if the eye will make an effort within its accommodative limits to focus the clearest and brightest image possible upon its retina, it follows that the eye will focus instinctively for yellow if emmetropic and make any reasonable accommodative effort if ametropic to get the yellow image plane upon its retina in order to secure the brightest and least blurred image possible.

Bichrome refraction, based upon getting the retina situated midway betwen red and blue, and therefore at yellow, not only presents a new, doubly-sensitive method of measuring ametropia in the human eye but offers the first and only method so far devised for making eyes emmetropic for a specific wave-length and that the wave-length accepted as the standard of measurement throughout the whole realm of science. Thus aside from the undoubted utilitarian value of the method there is reason to hope it will prove to be the means of placing the measurements of the human eye upon as definite and precise a standard as the measurements of other optical instruments—but we do not expect this to be brought about without a struggle.

One of the greatest obstacles to the general acceptance of bichrome refraction, even to an unbiased consideration of its principles, will be the firmly implanted idea that only when *"the"* image of an object is focused precisely on the retina can that object be seen clearly. Prac-

tically no thought has been given to the possibility of the retina accepting an image in any one of the many color planes other than the yellow even though it has been known for years that 1.8 diopters of chromatic accommodation may be made available thereby without bringing the ciliary muscle into use at all.

This idea is based solely upon a geometric conception of the eye being a mechanical, box-like, human camera, destitute of all adjustment except that of moving one definite image plane forward or backward by an increase or decrease in the curvature, and therefore in the refractive power, of the crystalline lens. The possibility of such a thing as physiologic or psychologic adaptation outside the eye is barely conceived and still less admitted and applied.

It will require no little courage on the part of those thoroughly imbued with this geometric or purely mechanical concept of accommodation to accept the theory that a low plus spherical may be added to one eye and a low minus to the other without necessarily disturbing the mechanical accommodative relationship between those two eyes. Many will dismiss the theory as ridiculous, as were dismissed the astronomical theory of Copernicus, the circulation of the blood theory of Harvey and the germ theory of Pasteur, all of which, with innumerable similar instances, are universally honored today.

But consider. The human eye is not achromatic. With its mechanical accommodation fixed it focuses red light at one point, violet at another and orange, yellow, green and blue at intermediate points. Thus the eye has a different refractive power for each color. This is generally known, and as generally disregarded. Some day, however, and soon we hope, when Optometry aligns itself with all other branches of optical science, it will not speak of an emmetropic eye indefinitely and inexactly as at present but of an eye definitely and exactly emmetropic for yellow. Such an eye, statically emmetropic for yellow, is at the same time hypermetropic for orange and red while myopic for green, blue and violet. Conversely an eye emmetropic for red is myopic for every other color while one emmetropic for violet is hypermetropic for every other color.

Some half-diopter hypermetropes experience severe eyestrain, others do not; the former dependent upon correcting lenses, the latter refusing to be burdened with them; the former *seeing* no need but *feeling* a very definite need for correcting lenses, the latter neither seeing nor feeling any need whatever; the former seeing clearly, we know, because were he willing to accept the half-diopter blurred images and not psycho-reflexly clearing them with a half-diopter accommodative effort, he would have no eyestrain; the latter either seeing clearly by making a half-diopter accommodative effort which evidently does not overtax him or making no mechanical accommodative effort and being satisfied visually with the half-diopter blurred images, *or selecting the green image-plane and thereby getting clear images without exerting any mechanical accommodative effort whatsoever.*

Heretofore we have limited our considerations within the narrow confines of purely mechanical accommodation, a purely geometric-anatomic concept. Now it would seem to behoove us to extend our views to take in the possibility of an auxiliary chromatic accommodation or adaptation.

In order to do this it will be necessary to liberalize the view we have held to so long and so tenaciously in relation to our mechanical accommodation. Primarily the assumption is that if we are focused for near we cannot see clearly for distance. On paper, geometrically, that may seem true but as a matter of fact it is not so. For example, I sit on my porch and look off at one fixed distant point, say half a mile; while doing so a number of things are in sight of which I am fully conscious simultaneously; just under my eyes about 18 inches away are my writing table and the arm of my wicker chair, each strand of which is discernible; three feet away is the screen, whose fine meshes are also clear, that is, I am conscious of no such blur as geometric optics leads me to expect; five feet away is some laurel and twenty feet away a dogwood tree, all still clear; cross the road are trees and then trees and more trees running off to the hills in the distance silhouetted against the sky; as I gaze fixedly at the distant hills every object within my field of vision is essentially equally clear, I am *conscious* of no real blur. Of course, some blur must exist somewhere in that range, rather some softness, as they say in photography, but certainly nothing like what should be expected if our mechanical accommodation be what we assume it to be or if that be the only form of accommodation we possess. While making the above observations a + 1.75 D. S. presbyopic correction is being worn but the reading addition can be removed and with the distance correction only in use the various objects in the various planes can still be seen with apparently equal clearness, i. e., equal "softness."

Let every reader truly interested in the subject of bichrome refraction make these simple observations. Wherever he may be at this moment let him look up and off and say candidly whether or not he can differentiate the clearness of objects at 6, 60 or 600 feet distances, as he fixates any one point. We have accepted so implicitly the geometric, diagrammatic conception of accommodative focusing upon the retina that we have permitted unconsciously our common observational powers to be lulled to sleep. Make these observations, test them from every angle, and ponder them carefully and we must conclude that the human eye, rather the human seeing apparatus, has a far looser adjustment, a far wider tolerance, physiologically and psychologically, than the strict mathematical laws of optical imagery indicate physically.

If mechanical accommodation be the all-embracing factor, if this be all that is involved, what gives this wider range, this greater depth of focus? Chromatic adaptability accounts for some of it on the basis that an eye is not myopic until it is myopic for red, nor hypermetropic until hypermetropic for blue.

To comprehend the full significance of bichrome refraction and to develop proof of its soundness require that we establish in proper order the underlying basic principles of photometry, blur circles or circles of diffusion, dispersion, chromatic aberration, achromatism, monochromatism, polychromatism, sensory acceptance, color sense and color blindness. In so doing few, if any, new principles need be touched upon, the real need calling for a correlation of old established principles which have been kept, for some unknown reason, in isolated, air-tight compartments.

If we can but take the salient features of these well known phenomena and weld them into a workable whole there is every reason to believe that we can double the sensitivity of any former subjective check technique.

First, then, we will review the divisions of the subject just enumerated. Second, we will append a list to each division which by no means is intended as a biblography but which does afford an easy means of filling in some detail if that be desired. And, third, we will attempt to correlate these formerly isolated values into a usable system.

Photometry

The procedure of comparing the intensities of light sources is called photometry. Its basic law, called the inverse square law, predicates that the illumination of a surface by a single source varies inversely as the square of the distance. Thus at twice the distance from a given source there will be one-fourth the intensity; at three times the distance, one-ninth the intensity; at four times the distance, one-sixteenth the intensity, and so on.

The Rumford shadow photometer, the Bunsen grease-spot photometer, and the Lummer-Brodhun photometer come at once to mind but must be dismissed immediately because we are to deal with colored light intensities and such photometers are useless where the light sources to be measured have even the slightest difference in color. The photoelectric cell has been used to measure the intensity of radiation but in so far as it is not equally sensitive to all colors it, too, must not be used to measure the intensity of illumination of the colored filters used in bichrome refraction.

The Flicker photometer is applicable for accurate comparison and Laurance suggests that a comparison of the intensities of two different colored sources may be made by occlusion, using for that purpose a series of properly graduated smoked glasses. Occlusion measurements, however, are not trustworthy because of the Purkinje effect wherein the bright area of the spectrum moves from the red toward the blue end as the intensity diminishes. Hence, if two sources of light be equalized one red and the other blue and then their intensity of illumination diminished the blue will appear brighter than the red.

Thus in bichrome refraction the two colored filters must be equalized under a given intensity and that intensity maintained.

Already there are forms of this test offered which ignore these essential requirements and which by vitiating the results may bring a most valuable adjunct to subjective testing unjustly into disrepute.

Tentatively we advise looking askance at any bichrome test filter made of one thickness glass or celluloid and to measure directly the quality and quantity of the radiations of any filters offered or to demand proof that they meet the essential requirements both as to their monochromatism and equality of intensity.

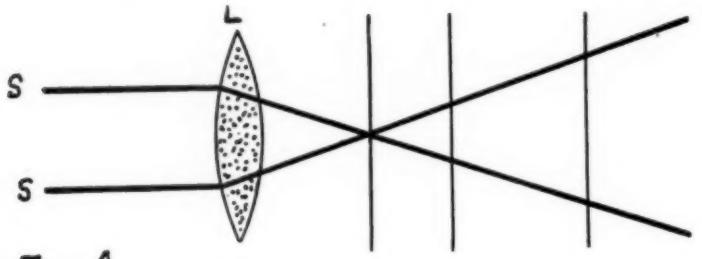

Fig. 1.

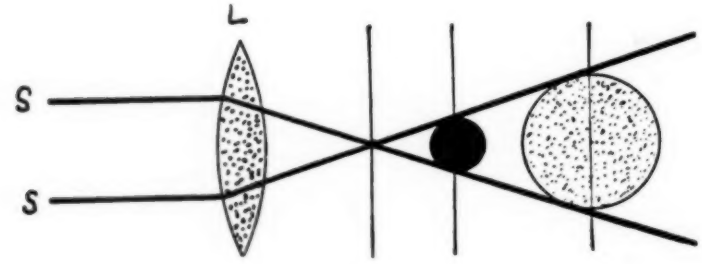

Fig. 2.

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Blur Circles

So much is known about blur circles or circles of diffusion by optometrists that it seems almost presumptuous to touch upon them at all. Touch upon them is all we will do but touch upon them we must in order to bring out one salient feature which is the very basis of bichrome refraction.

Trusting so implicitly to geometric optics as the one and only way of attacking our problems in optometry, we have come to think of blur

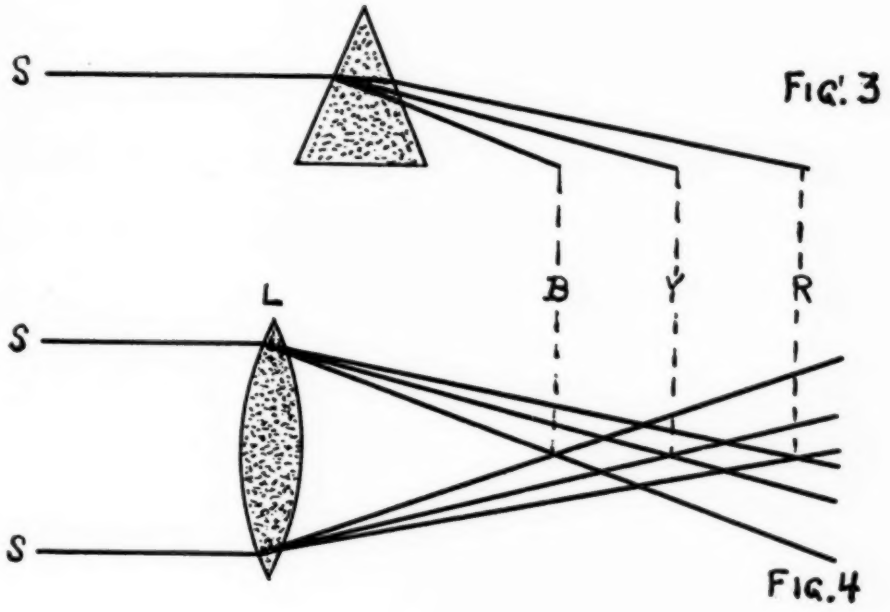

FIG. 3

FIG. 4

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circles as of little or no importance, as merely larger circles of light encountered as a screen is moved away from the focus of a lens, the blur circle increasing in size as the screen recedes.

Thus rays emanating from a light source, S, Fig. 1, are focused by the lens L at F. If a screen be placed at F, a so-called point of light will be imaged upon it; in reality, contrary to geometric conception, this image is never a true punctual image but one made up at best of a series of very small blur circles. However, at F will be found the smallest, sharpest image procurable. As the screen is moved to B a larger blur circle results and at B′ a still larger, and so on indefinitely.

If, now, to this we correlate the inverse square law of photometry just mentioned we will recognize the fact that a blur circle is bound to be a *dull circle.*

Geometrically accurate diagrams have succeeded quite naturally in hiding this fact.

For a proper understanding of the theory of bichrome refraction it is essential that this most important feature be fully appreciated.

Keeping in mind that this paper is but an introduction to bichrome refraction many collateral details are reluctantly omitted. To offset this omission we add here, as at the end of every other section, a care-

fully selected list of references bearing on these details.

Suffice to say therefore that a blur circle is a dull circle as shown in Fig. 2, wherein S is again the source of light, L the lens, F the focus, while at B and B′ are blur circles which are dull circles because the light which was concentrated at F is now spread out over a much larger surface at B and over a still larger surface at B′.

Put in more homely fashion, consider F a generously thick lump of butter on a small oyster cracker; it is obvious that if this same amount of butter be spread out and made to cover evenly the entire surface of a regular soda cracker, B, the layer of butter will be pretty thin and still thinner if made to cover a large ship-biscuit, B′.

In these blur circles with which we are to deal in our consideration of bichrome refraction there is no more light at B′ than at B or at F, there is merely a difference between concentration and spread.

Blur circles are indeed dull circles.

Index of Refraction and Dispersion

The index of refraction is the ratio of the sines of the angles of incidence and refraction for a ray of light passing obliquely from one medium into another.

The index of refraction is found to be different for lights of different colors, that is, of different wave-lengths. Therefore all colors are not deviated through the same angle. Hence a glass prism, a lens or the eye has a different effect on each color. Red is deviated through the smallest angle, orange a little more, yellow still more and so on through green, blue and violet as shown in Fig. 3. This difference in deviation is called dispersion. It exists to a measurable dégree in the eye and is utilized to advantage in bichrome refraction.

In a few remote instances this is not true and red is bent more than violet but this phenomenon, anomalous dispersion, has no bearing, yet, upon the practical application of bichrome refraction.

Chromatic Aberration

It is an easy transition from Fig. 3 to Fig. 4 which shows the principle of dispersion applied to a lens, resulting in chromatic aberration.

For the purposes of this paper it is necessary to go a little further than the simple conclusion that chromatic aberration merely causes white light to be broken up or dispersed causing, in turn, colored fringes to surround the images produced by other than achromatic lenses. Perfect achromatism has not been mastered.

The eye possesses chromatic aberration. Hence if none but red light passes into an eye a single, well defined red image free from color fringes will be formed in what we will term the red focal plane; if only

yellow light enters, a single, well defined yellow image free from color fringes will be formed in the yellow focal plane; if only blue light enters, a single, well defined blue image free from color fringes will be formed in the blue focal plane. This would be true of course for every primary color.

Each of these images, however, would differ from each other in both *size* and position.

Thus by moving the retina backward and forward and allowing light of only one color to enter we can make an eye emmetropic for any color desired. Or by keeping the retina fixed and varying the power of the refracting system for each color a similar result can be obtained.

Now, when sunlight enters an eye, light of every conceivable color is involved and we have all these images of different color and of different size formed in their respective color planes. The retina can be at one focal plane only and receive only one color image clearly defined at one time, all the other images being larger or smaller and either in front of or back of the one focused on the retina. Thus does chromatic aberration create color fringes.

Further correlation is now possible. Recalling that blur circles are dull circles and that chromatic aberration creates a series of colored blur circles we may conclude that these colored blur circles are also dull circles and ordinarily not noticeable although known to create colored fringes about the edges of all images not formed by purely monochromatic light.

The eye if able to do so selects the yellow focal plane under ordinary conditions because it is the brightest and because herein lies the circle of least diffusion. But if the eye be hypermetropic and forced to strain painfully to bring the yellow focal plane to the retina it may elect to accept the green, blue or violet plane instead. If it be myopic it may learn to accept the orange or the red plane instead of the yellow. This has been termed sensory acceptance.

Thus to bring both of a pair of eyes into focus for the same color plane, and especially the yellow plane, seems to us a genuine improvement in optometric technique and this is made possible by an application of the principles underlying bichrome refraction.

The fixed, inelastic concept which geometric optics has established of the chromatic aberration of the eye being an out-and-out defect instead of possibly a wise provision of Nature to allow a wider range of comfortable focal adaptability has retarded progress long enough. We urge that Optometry remove this inhibition.

If evolution has made the yellow plane the choice plane of the normal eye, if the yellow plane is the best plane for which to make the eye emmetropic, if it be an advantage to have both eyes corrected for the same plane and that the yellow, then the bichrome principle

deserves our most serious consideration in so far as it offers the best means, so far as we know, of accomplishing this desired end.

The Spectrum

Right within his own field the spectrum challenges the highest research endeavors of the optometrist, not only, however, on a geometric optics basis but from a physiologic and psychologic viewpoint. Only the most elementary principles can be touched upon here.

There are two kinds of spectra. The prismatic or spectrum of refraction and the normal or spectrum of diffraction. The former obtained by a prism, the latter by a fine-line grating.

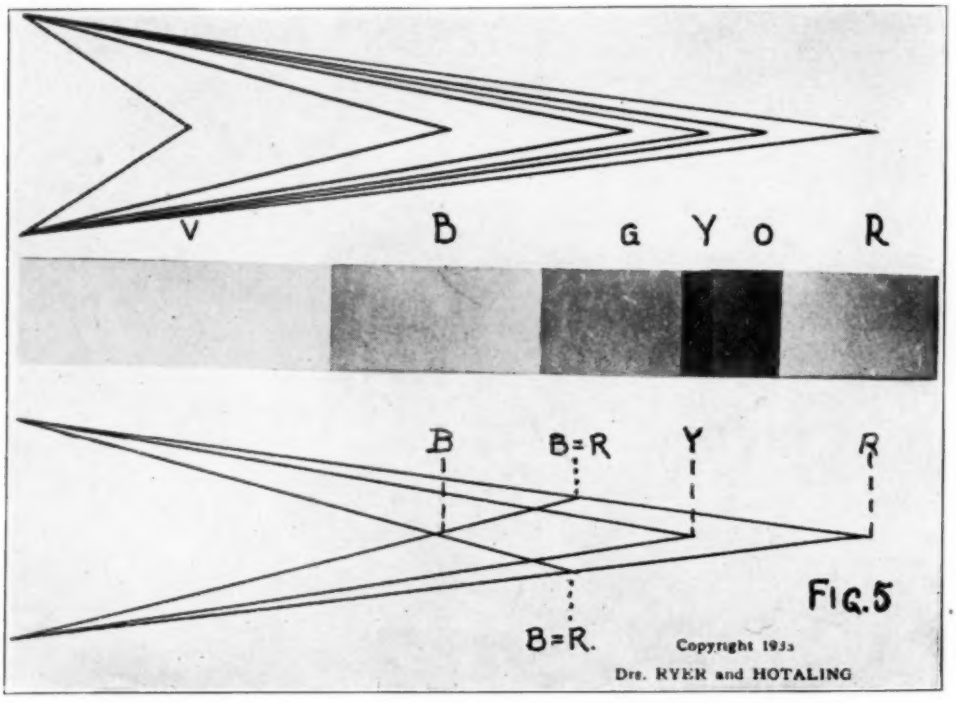


FIG. 5

The chief distinction is that in the prismatic spectrum the colors at the red end are compressed and at the violet end widely spread out; this disproportion varies with the power and with the refractive index of the prism but it places the yellow, in which we are so deeply interested, nearer the red end instead of in the middle. In the normal spectrum the distance between the colors, on the contrary, is proportional to the difference of the wave-length and this relation obtains in all spectra of diffraction, the yellow being in the middle, the red and orange

occupying one half, the green, blue and violet the other half. Incidentally, prismatic spectra are relatively brighter than spectra of diffraction.

The eye has no grating, it has high prismatic power, hence forms spectra of refraction and thereby complicates our problem a little.

Fig. 5 shows a prismatic spectrum and indicates at once why some care must be exercised in selecting filters that are to be used in bichrome refraction. The delicacy of the test depends upon contrasting the clearness (strictly the "softness") of two objects, one of which is illuminated by monochromatic blue and the other by monochromatic red radiation.

The primary aim is to get the eye focused statically for yellow, hence if two yellow filters were selected there would be no contrast and no point to the test; if an orange and a green filter were selected there would be some but not nearly as marked a contrast as that which is afforded by blue and red. Contrast can be obtained with green and red or with orange and violet filters but when these are evenly balanced yellow will not lie half-way between and to have the focus for yellow lying exactly half-way between two sets of equal-sized blur circles is the very essence of the test.

In a word, if care be not exercised to select filters of definitely balanced, sharply cut-off wave-length transmission, one of two faulty conditions is bound to result, either the focus for yellow will not lie on the retina when the blur circle for one color equals that of the other or the patient must be called upon to do the impossible and state when one colored test object is just sufficiently that much more blurred than the other to insure the yellow lying on the retina. Either condition precludes all possibility of practicability and accuracy.

If, therefore, in general terms, we use a monochromatic blue filter transmitting only light whose wave-length is essentially 4,500 A. U. and a red filter transmitting only light whose wave-length is essentially 7,100 A. U., we can employ a highly sensitive yet extremely simple means of knowing that we have the retina in focus for yellow light of wave-length essentially 5,800 A. U., midway between the two others.

No one who has not actually sought true monochromatic filters has the least conception of the difficulties involved. For example, take the bluest glass one can find, it will be found, under the spectroscope, to transmit red as well as blue, but more of that under Filters.

Monochromatic and Polychromatic Light

It is only in extremely rare instances that pure, unmixed colors are seen in Nature. Color-mixtures predominate. Numerous color-mixtures exist which our eyes cannot distinguish from the pure, monochromatic, spectral colors. The ear is capable of analyzing tone-mixtures but the human eye does not possess the faculty of analyzing color-mixtures in an analogous manner.

The only natural objects we know of which transmit monochromatic light are human blood and the blood of a few other animals.

The outstanding example of polychromatic or heterogeneous light is sunlight, every color conceivable being contained therein. The first step toward a proper appreciation of the potential values which lie in bichrome refraction must be a recognition of the fact (now generally overlooked) that in dealing with a test chart of black letters on a white ground we are dealing with polychromatic or heterogeneous light.

Isolated light of one color, of one specific wave-length, is most rare and most difficult to create. Practical difficulties lie in the way of obtaining glass which will transmit one and only one wave-length. Take a piece of what appears to be the bluest glass obtainable, cobalt for example, and it will be found to transmit some red and violet as well as blue light, cutting out much but not all of the intermediate colors.

It has been known for years that the human eye cannot focus with equal clearness two monochromatic objects of different color at the same time from the same distance.

Thus, for example, if a static eye possessed just sufficient refractive power to bring the rays from a monochromatic blue object to a focus on the retina, it is obvious that rays from a monochromatic red object at the same distance, being bent through a smaller angle, would be intercepted by the retina before they came to a focus, producing thereby a red blur circle. If a static eye had sufficient power to bring the rays from a monochromatic red object to a focus on the retina the rays from a blue object placed at the same distance, being bent through a relatively greater angle, would meet and cross before they reached the retina and in their continuation produce a blur circle at the retina. In the first case the result at the retina would be a bright blue point surrounded by a dull red blur circle and in the second a bright red point surrounded by a dull blue blur circle.

Now a static eye with a refractive power just sufficiently greater than the first and just sufficiently less than the second mentioned above would produce two dull blur circles, one blue, the other red, equal in size. It is further obvious that once this balance were established the slightest increase in power would tend to sharpen the red and dull the blue correspondingly and vice versa, the contrast being doubled because one is moved as much nearer sharp focus as the other is moved away.

This is the principle underlying bichrome refraction.

Bichrome Filters

There are some red glasses which afford a fairly sharp cut-out in the red. All of the green glass and green celluloid we have examined transmit besides green considerable red and some blue and a little yellow.

Suffice it to say that one of the most difficult undertakings in

optics or in glass-making is the production of monochromatic filters. We do not believe the colors needed for bichrome refraction have been obtainable in single sheets of glass or celluloid. The secret lies in combining filters in such a way as to isolate light of essentially one wavelength.

If, therefore, a test is to be based upon monochromatic filters as is the bichrome check test, too much care cannot be exercised in obtaining as near monochromatic transmission as possible. The sharper the cut-off and the further and the more uniformly each color is removed respectively from yellow the more delicate and the more accurate the test.

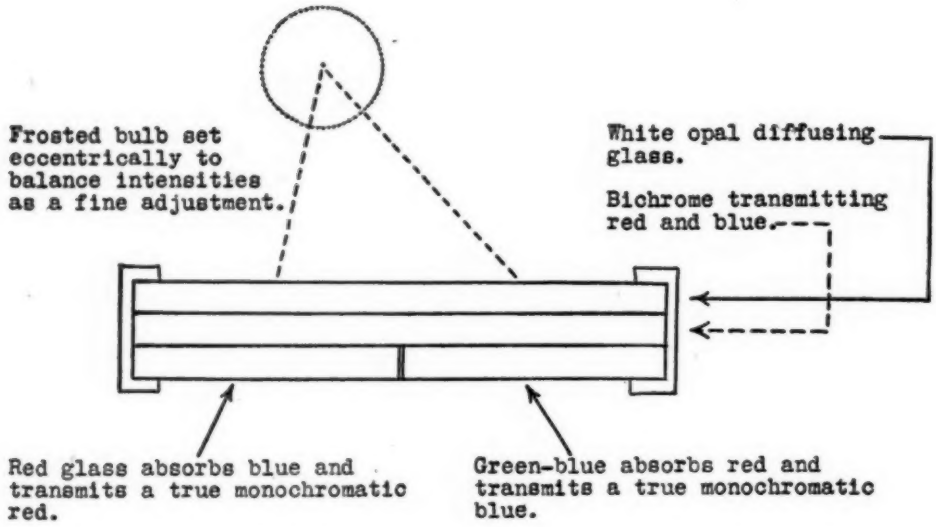
Thus, as the accuracy of the test depends upon having unmixed red light coming through one filter and unmixed blue through the other, that accuracy is imperiled the moment either filter transmits any of the opposite colored light as can be readily understood by assuming that each transmits as much of the other color as it does its own, in which case the filters would be alike, the contrast eliminated and the test destroyed. Matters are made still worse in this respect if one, as the blue is prone to do, transmit a much higher percentage of the other color and thus destroy the all-essential balance.

Of all the glass and celluloid samples we have examined we have found none of *single* thickness which did not pass more or less of most of the colors of the spectrum favoring only the predominating hue.

Hence, however blue the blue or however green the green or however red the red glass looks in any test offered trust none until subjected to spectroscopic analysis. The small direct vision hand spectroscope is amply capable of disclosing the many culprits among filters.

But assuming trustworthy filters are secured so far as their monochromatic transmission is concerned, it is still further essential that they be so illuminated as to be equally intense, no easy matter with filters of blue and red. Here is a call for correlation of photometry and spectrometry.

The only successful attempt we know of was made by Pech. He realized that beside monochromatism, it was necessary to obtain the same degree of brightness for the blue and the red filter, taking account of the difference in sensitivity of the eye for the two radiations. As blue is less stimulating he made a preliminary filtration by means of a bichromatic glass which allowed the blue and the red to pass, but with different absorptions, the red being absorbed more than the blue. In this manner the inequality in the intensity of the two colors was compensated. It remained only to eliminate the red on half that glass to produce a proper blue and to eliminate the blue on the other half to produce the proper red, side by side. The high power light bulb was set eccentrically so as to adjust the balance precisely. Back of the two layers of colored glass was placed another of white opal to diffuse the illumination and diffusion is further aided by using a frosted bulb.


Frosted bulb set eccentrically to balance intensities as a fine adjustment.
White opal diffusing glass.
Bichrome transmitting red and blue.
Red glass absorbs blue and transmits a true monochromatic red.
Green-blue absorbs red and transmits a true monochromatic blue.

Drs Ryer and Hotaling. Figure 6.

TOB.

Fig. 6 shows this arrangement diagrammatically.

The conditions which have to be met in order to make any bichrome check test valid is that a pair of filters be selected for use at that distance which insures the yellow rays from infinity coming to a focus in that plane wherein the respective blur circles of the two filters are equal in size and intensity. Thus, Fig. 5 shows that unless special care be exercised the fundamental conditions will *not* be met.

Here it is seen that the blur circles are equal in the plane designated B = R; it is here that yellow should focus; it does not; hence, remembering that no yellow is used in the test and that full dependence is placed upon it being invisibly midway between the blue and the red of the filters, either the testing distance or the wave-length transmission of the filters, or both, must be changed in order to meet the required conditions. If a twenty-foot testing distance be used the choice of filter colors seems limited to an orange-red on one side and a yellow-green on the other which means that some yellow light is present in each filter, cutting down the contrast, destroying the monochromatic integrity and vitiating the test.

The ideal would consist in selecting a red as far away from yellow as possible, just inside the infra red zone, and a blue as far on the other side of yellow as is needed to insure its rays crossing those of the red in the focal plane of yellow.

This ideal has been closely approximated by one and to our knowledge only one of the bichrome tests thus far offered. We must

urge, therefore, upon those contemplating the adaptation of Bichrome Refraction to their practice extreme vigilance in guarding against either wilful or unconscious misrepresentation, some of which has already got by.

Color Sense and Color Blindness

Sir Isaac Newton, the discoverer of the heterogeneity of white light, must have been inherently a keen, cautious observer. Yet some of his deductions have been proved to be erroneous. The nature of these errors indicates that he had a slight defect in his color vision. With the great master of color thus exposed to a disturbance in the color sense it would seem to behoove each of us to be on our guard. In this case, being on guard signifies not only that we obtain a thorough knowledge of the state of our own color vision but that we test thoroughly the color sense of each patient.

We pointed out most significantly that many of the weird diagnoses in campimetry and perimetry were presented by men who had overlooked color sense defects in their subjects, interpreting contracted red and green fields as symptoms of toxic amblyopia, brain tumor or what not, when in truth the red and green fields were contracted simply because the cases were cases of red-green color blindness. We have proof of this.

We will not attempt here to cover the ground we think should be covered by every optometrist in an exhaustive study of color vision and color blindness but will urge most earnestly that Bichrome Refraction, dealing specifically with monochromatic red and blue light, be guarded against this source of error and misjudgment.

This merest hint must make it obvious that a patient who is color blind to red is not a fit subject for Bichrome Refraction. Partial red blindness is more likely to cause trouble if undetected than complete red blindness because it merely disturbs the balance of the filters and leads insidiously to incorrect judgments whereas total red blindness causes the red filter to appear black and immediately exposes itself.

Much to our surprise we found all green blind cases responding more sensitively to this test than normal cases. The failure to anticipate this, for which there is no excuse, was due to the failure to correlate well known facts, a failure which generally has been the chief factor in holding back this important work many years. We knew how difficult it was to create a monochromatic blue filter, some of the green always sneaking through beside the blue, but the green which we could not screen out with glass is here screened out most effectively by Nature so that between our blue filter which screens out all but blue and a little green and the color blindness to green we have the green effectually eliminated with the result that the best pair of red and blue filters thus far obtainable is made almost perfect automatically if green blindness alone exists in an eye.

The fact must not be overlooked, however, that while color blindness to green enhances the accuracy of the red and *blue* filters, it vitiates the red and *green* filters by upsetting their balance or eliminating the green altogther.

While the importance of uncovering these color vision defects wherever they exist must be stressed it is well to keep in mind that such cases are relatively rare. Out of a thousand cases, taken in the order of their regular appearance for examination, we found a fraction over 17 per cent affected with some form of color sense deficiency. Eliminating the green-blind, a small but very important number remain which should not be overlooked but which, if eliminated, need be no deterrent in the application of Bichrome Refraction. No single color vision test may be trusted to uncover all forms of color sense deficiency. Those referred to above were discovered by means of the color lantern of the Genothalmic Chart in combination with either the Ishihara or the Stilling pseudo-isochromatic test.

At the risk of seeming to over-emphasize the need for general routine color vision testing, we cite two cases quoted by Abney which show indirectly how well founded is the contention that the Bichrome Check or any other test based on color (and, after all, what test in optometry, even among those with white light, is not based on color?) should be preceded by a trustworthy test of the color sense.

(1) One case is reported in which the absorption by the macula pigment seems to be absent, coupled with a considerable amount of red blindness, causing the patient to mistake blue for red. (2) Another case is reported in which the amount of pigment in the retina is so great that it practically cut off a large portion of the blue end of the spectrum and was believed at the time to be a case of violet blindness. He saw two colors, red and black. He called all greens and blues, black; greens, however, he called bright black, blues being darker black; yellows he called white.

Rare cases, true, but cases whose defects should be uncovered by the optometrist not merely in relation to Bichrome Refraction but in relation to many if not all other departments of optometry. In other words, let us not dodge our duty to test for color blindness by dismissing Bichrome Refraction, because if missed color blindness remains a disturbing factor ready to plague us at every step in our work.

One of the latest reports is that there are in the world 50,000 partial color blind cases but only 125 cases of total color-blindness, 11 of which are in the United States of America.

It remains to be noted that for aphakic eyes a special set of color filters is required in order to apply the Bichrome Check Test, due to the fact that color sensations are disturbed in such eyes by the removal of the cataractous crystalline lens which has been absorbing blue.

Having broken down the compartmental partitions and merged the photometric inverse square law with blur circles, blur circles with

dull circles, dull circles with chromatic aberration, chromatic aberration with sensory acceptance, sensory acceptance with chromatic accommodation, and chromatic accommodation with monochromatic test filters, we are prepared to consider by what means and by what technique the principle, known as Bichrome Refraction, emerging from this correlation may be applied in the practice of optometry. Once that principle is understood the application is very simple.

The Means

Convinced, by such study of Bichrome Refraction as we were capable of bringing to bear upon it, that it will prove good optometric practice to establish the standard of bringing the eye to emmetropia specifically for yellow (sodium) at infinity, we perceived real worth in the two-color check test designed especially to make possible this standard.

It presents side by side for easy, simultaneous comparison, two similar sets of graduated letters, one surrounded by a field of monochromatic red, the other by an equally intense monochromatic blue.

The sizes of the letters are arbitrary as well they may be because we have demonstrated that fine lines are superior and that almost any set of characters will answer the purpose, which is not critical differentiation but easy comparison. Some of the best results obtained, with both trained and untrained observers, were with a single dot on each filter.

The best filters we have found thus far are balanced for use at 55 inches. It cannot be emphasized too strongly that this is the only distance at which the test can be made accurately with this particular set of filters. At other distances the two sets of test characters can be made equally "soft" or balanced readily enough, meaning that the retinal blur circles have been made equal in size, but only when those blur circles are equal for objects set at a distance of 55 inches (1.4 M.) does the focus for yellow at infinity lie in the same plane, which is, of course, the retinal plane.

With no little difficulty, Dr. Pech, aided by his chief assistant, Dr. Imbert, as well as by the optician, Mr. Peter, and the master glass workers, Messrs. Appert, obtained satisfactory monochromatic filters, and we are indebted to Dr. J. C. Copeland and I. B. Lueck, B. S., for the English translation of this work.

Our laboratory and clinical experience with these and a number of substitutes shows these to be far superior to the others but still open to further refinement in minor details.

Those who use and are satisfied with some of the red and green filters miss apparently the most fundamental aspect of the entire issue. These filters are not monochromatic red and green, as they appear, but are highly polychromatic, as any spectroscope will show, hence they can be balanced but cannot be *unbalanced* except with lens power so high as

to take away much corroborative value. Without *monochromatic* filters the basic bichrome principle is lost. The admission that these red and green filters may be used at various ranges condemns them to one understanding the true bichrome principle.

For example, in hundreds of cases, mostly the average types which consult any optometrist but including some children as young as four years, mental defectives, senile cataract cases and amblyopes, a correction which balanced the red and blue monochromatic filters could be tipped either way by the addition of a +0.12 or a —0.12 S., the plus eighth making the red stand out definitely clearer than the blue, and vice versa.

In many of these cases, while the red and green filters are pronounced balanced, an addition as high frequently as + or —0.62 fails to unbalance them while still grosser changes merely blur both sets of letters beyond recognition without unbalancing them appreciably and do not most of us rightfully expect to be within 1.25 D. of correction without check tests?

The true test of the practical value of any pair of filters does not consist in ascertaining whether or not they can be balanced, nor in whether or not they can be unbalanced, but in whether or not once balanced a +0.12 will throw the red clearer than the blue and a —0.12 will unbalance the other way and throw the blue clearer than the red.

Unless that distinction is thoroughly appreciated the principle of Bichrome Refraction is missed and unless the filters are calibrated on that principle for use at some one distance and used at that distance, they may mislead rather than aid.

We had found case after case able to differentiate with ease approximately one-sixteenth diopter changes, that is, cases wherein with the red slightly clearer the addition of a —0.12 makes the blue clearer and not just equal, as it would were a full eighth needed to balance.

To those who have had no experience with strictly balanced monochromatic filters such claims may seem exaggerated but they are literally true and not to be wondered at if it be remembered, first, that any method of subjective testing is more precise under monochromatic illumination which eliminates the blur circles of polychromatic (white test chart) illumination and the accompanying play within the chromatic sensory acceptance range; secondly, that in ordinary testing we move the focus off the retina in one direction a given amount for a given power, whereas in true Bichrome testing the effect of any lens change is doubled because we deal with two images simultaneously, moving one as much nearer the retina as we move the other away and thereby clearing one as much as we dull the other; thirdly, that in ordinary testing the patient must compare one phase with his memory of another as the check lens cannot be on and off at one and the same time, whereas in Bichrome testing both phases are visible and comparable simultaneously; and, fourthly, that in Bichrome testing the clearing of one monochromatic image and the blurring of the other is very definite whereas similarly small changes in the correcting lens for a polychromatic test object, like

a black and white test chart, become increasingly difficult to denote as the precise correction is approached.

To appreciate thoroughly the sensitiveness and simplicity of Bichrome Check Test the instrument itself must be used; words alone cannot do justice to it. But "An Introduction to Bichrome Refraction," which this paper purports to be, does not imply an actual demonstration of an instrument nor even a detailed description of the associated technique.

Hence we must content ourselves with a brief description of the basic technique offered by Pech and Imbert, together with an outline, but outline only, of some of the modifications in technique we have developed in our limited study of the subject.

The Basic Technique of Pech and Imbert

It is indispensable that each eye be examined separately.

The red and blue filters must first be made to appear about equally intense.

If highly myopic the patient sees neither red nor blue filter clearly; if slightly myopic the red alone is seen clearly and the minus lens which makes them equally clear is the exact correction. A stronger minus should cause the red to be seen less clearly than the blue and a weaker minus should cause the blue to be seen less clearly than the red.

If highly hypermetropic the patient sees neither red nor blue clearly; if slightly hypermetropic the blue alone is seen clearly. The plus lens which balances is the exact correction where a stronger plus should make the red clearer and a weaker plus the blue clearer.

With the distance error corrected presbyopia should be looked for. A non-presbyope continues to see the red clearly in spite of the addition of plus power of at least 0.50 D., and the blue clearly in spite of the addition of at least —5.00 D.

If the patient be normal for distance, *i. e.*, balanced at 1.4 M., but cannot see the blue clearly with the —5.00 D., he is presbyopic and should wear reading correction.

The correction for near is the difference between 5.50 and the strongest minus that still permits the blue to be seen clearly.

For astigmia Doctors Pech and Imbert use the circles of their ericiscope which are not on the Bichrome Check Test used in this country.

Furthermore they have outlined special applications of Bichrome Refraction in cases of aphakia, partial color blindness, and faulty nutrition, details of which are not in order until the basic technique is established.

In our opinion Doctors Pech and Imbert have made the technique seem more complex than in reality it is. This may be due solely to the difficulties of translation.

The Scope of the Authors' Investigations

We find no change need be made in anyone's technique. Arrive at subjective correction by any route desired. Check that result by noting whether or not a +0.12 S. makes the red clearer than the blue and a —0.12 S. the blue clearer than the red. Essentially this represents Bichrome checking.

We find that in young cases a —0.25 S. overcorrection is found unless the convergence stimulus is eliminated, which, of course, should be by using 4.$^{\Delta}$, 4.5$^{\Delta}$, or 5.$^{\Delta}$ base-in prism power for interpupillary distances of 56 mm., 63 mm., or 70 mm., respectively, as a 1.4 M. working-distance allowance.

In myopic cases we see signs of the pseudo type when an addition of base-in prism power definitely reduces the spherical power called for. We add base-in prism so long as it continues to reduce the minus spherical demand and prescribe that lowered minus in combination with whatever base-in prism is present in excess of the interpupillary distance equivalent.

We have demonstrated the feasibility of producing a pair of filters for testing at near.

We studied the blur points most delicately as base-in and base-out prism power is varied.

We see a menace in the advent of inferior, inaccurate filters, offered without any knowledge of or, worse, without any regard for their wave-length transmission, their balance or their monochromatism—qualities essential to accuracy.

We have demonstrated the possibility of using the sodium vapor lamp to recheck at infinity under monochromatic yellow illumination the correction found under Bichrome red and blue.

We have noted that while, without compensating base-in prism, —0.25 must be allowed in most youthful cases, a little more plus is accepted in some adult cases and have traced this to the blue absorption by the yellowing senile crystalline lens and a consequent shift in spectral values.

We have obtained a cross check by employing white lines together with black on red and blue backgrounds, in which case the white are clearer on the blue when the black are clearer on the red, and vice versa.

We can adapt Bichrome Refraction to complete subjective analysis by means of the stenopaeic slit.

In view of the fact that different colors form different sized retinal images in a given eye, we advance the hypothesis that the unequal retinal images of Ames and Gliddon may be made equal by using lenses of the proper difference in color.

We demonstrated in 1907 that myopic corrections can be reduced and hyperopic corrections increased under red illumination and that

presbyopia as high as 0.75 or 0.87 can be banished without lenses under violet illumination, and we can verify these phenomena today.

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Discussion:

DR. B. H. BOHALL: Drs. Ryer and Hotaling's paper is particularly valuable in that they point out that this test is primarily a check test. We are all agreed that objective methods used in refraction still require check tests of a subjective character. We should never lose sight of this.

In using this test we must remember that some practitioners will get better results than others. Dr. Ryer put particular emphasis on the necessity of selecting proper quality of filter. We must remember that some cases, with this test, do not show the same sensitivity as others. Thus while this test will show changes as low as $\frac{1}{8}$ of a diopter in some cases, it will not be sensitive in other cases by as much as $\frac{3}{4}$ of a diopter. I would like Dr. Ryer's opinion as to the procedure in the latter type case.

DR. RYER: In answer to Dr. Bohall's question, one explanation may be that referred to in the paper itself, namely, that the metabolic changes in the individual cause refractive changes in the media.

Another explanation may be that the patient does not properly understand what is expected of him. In general, the test should be done as quickly and as precisely as possible, and the patient be prevented from studying the test.

DR. G. D. OERTEL: I would like to know how the definite distance of 55″ is maintained during the examination.

DR. RYER: In answer to Dr. Oertel's question, the distance from the trial frame to the chart is carefully measured, either by markings on the wall, or by a string extending from the trial frame to the chart.

DR. L. L. BEACHER: I might suggest that in order to be certain that this distance is maintained during the examination, I have my patients stand during the test with explicit instructions that they remain fairly rigid.

DR. R. M. HALL: Can Dr. Ryer tell me what changes are observed in the refraction, as conducted by this test, when there is an increase in the blood sugar?

DR. RYER: In answer to Dr. Hall's query, workers who have followed that line of investigation have reported that with an increase of the blood sugar, the red becomes clearer.

DR. M. M. HARMON: I would like to know what effect there is in doing this test when the cylinder correction of the patient is not, or has not been, accurately determined.

DR. RYER: Referring to Dr. Harmon's inquiry, we have considered this experimentally when the proper cylinder is removed during the test and found that even the test can be conducted almost equally as well, especially with low cylinders. Theoretically, the test might be conducted by the use of a stenopaic slit.

DR. B. BAER: I have tried using the test at 20′ by using an

ordinary illuminated chart with a pair of complementary colored filters. The test appears to be quite sensitive under these conditions.

DR. RYER: As Dr. Baer suggests, the test can be used at various distances provided the proper filters are selected.

DR. E. F. TAIT: In commenting on Dr. Ryer's excellent paper, I should like to point out that there are two basic assumptions that are applied in this test, and that these assumptions have, as yet, not been established as facts. First, the test is designed on the assumption that the human eye is the most sensitive for the sodium line. Secondly, that we have in the color aberration of the human eye a spectrum similar to a prism spectrum. When we realize that the eye is not of the same homogeneous structure as glass, we must be careful how we extend conclusions of the one spectrum to that of the other.

I shall be much interested in Dr. Ryer's future reports on this procedure after he has had an opportunity to gather and organize sufficient clinical statistics.

DR. NEUMUELLER: I concur with Dr. Tait in pointing out first that the high point of retinal sensitivity is usually toward the green-yellow rather than the yellow itself. Secondly, recent work on the spherical aberrations of the human eye shows that the caustic changes definitely from distance to near. There are also indications that the chromatic aberrations change from distance to near. It seems to me that the test should be made at a distance of twenty feet rather than fifty-five inches.

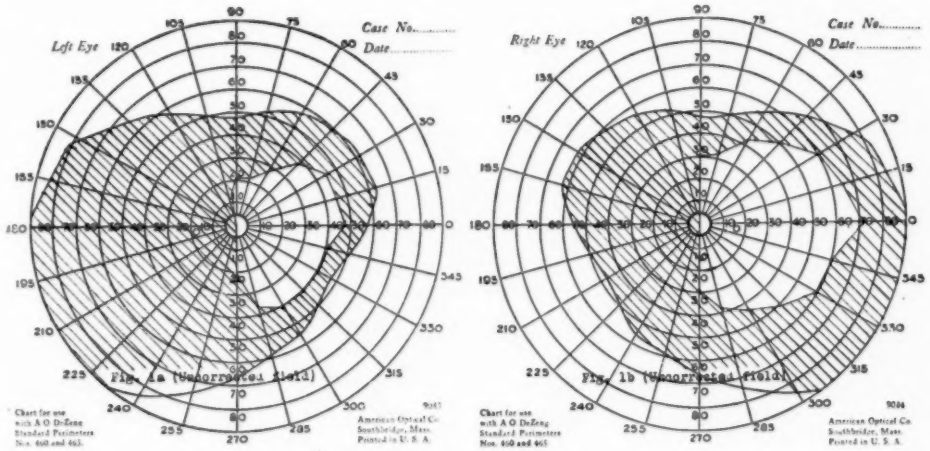
DR. RYER: Dr. Neumueller in urging that this test be made at twenty feet rather than at fifty-five inches misses a basic point. I stated clearly that the test may be made at any distance *provided* the filters are calculated for that distance. If he believes the filters he advocates are calculated properly for twenty feet, well and good. But all such filters I have seen are red and *green*. And he will find difficulty reconciling a green filter with the claim for high retinal sensitivity for green-yellow. If we accept the green-yellow plane as the one an eye should be corrected for, a green filter is obviously an incongruity. If he decides to place the eye in focus for the green-yellow plane rather than the sodium yellow, he should use a filter still further down in the blue toward the violet and see that all instruments with green filters be called in.

OPTICAL CORRECTION OF A CASE OF HOMONYMOUS HEMIANOPSIA*

Charles E. Jaeckle, B. S., O. D., F. A. A. O.
Newark, New Jersey

We are all familiar with cases of monocular blindness or amblyopia. Indeed, it not infrequently occurs that a patient consults the optometrist and learns only during the examination that one eye is to all intents and purposes blind. Now we know that the loss of the sight of one eye does not, as a rule, materially curtail the patient's activities. Yet everything possible is done for such patients.

It would seem, however, that little thought has been given (we find only two references in American literature) to the treatment of homonymous hemianopsia. Yet the individual suffering from this affliction experiences the most distressing symptoms. He does not see, with either eye or both eyes, any object, no matter how small or how large, lying on the blind side. Thus in right homonymous hemian-

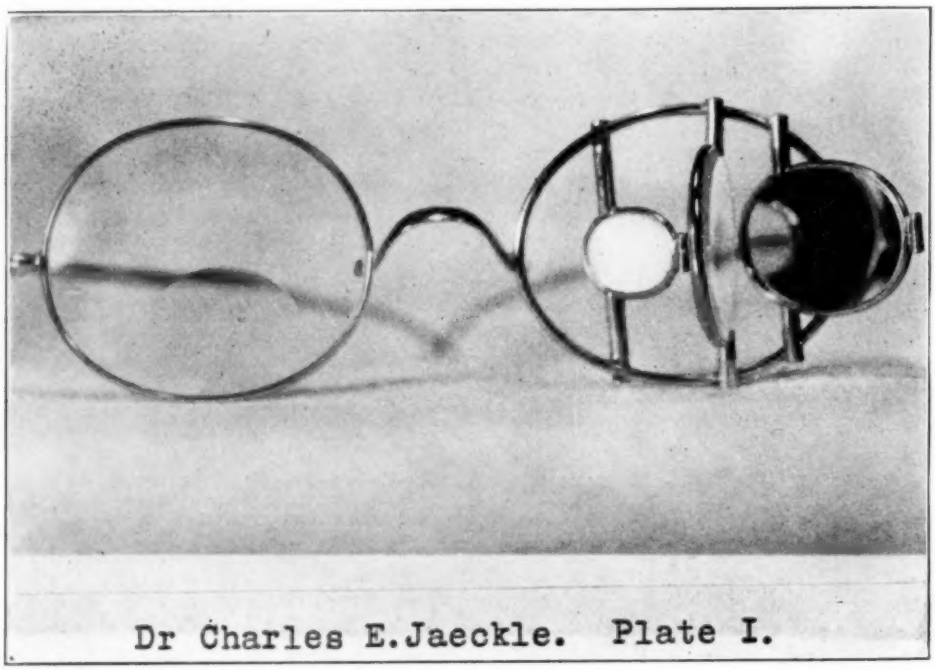


Dr Charles E.Jaeckle. Figures 1a and 1b.

*An abridgement of the material presented before the American Academy of Optometry at Baltimore. December 17, 1933.

opsia, the patient sees nothing to the right of the median line; in inferior hemianopsia, nothing below the horizontal plane, if the patient is looking straight ahead, for example. A patient might experience loss of a greater total area of the binocular field by concentric contraction, or other defects, than in the case of hemianopsia, without its greatly disturbing him; but the patient with total homonymous hemianopsia is truly mono-laterally blind. (Heteronymous hemianopsia—bitemporal or binasal—is not disturbing. The patient uses one eye for one side of the field, the other eye for the other side.)

The case reported is that of a woman, age 81, widow, who complained of poor vision at all distances, diplopia and polyopia, and



Dr Charles E.Jaeckle. Plate I.

bumping into objects—"on the left side, mostly." Things seemed to be out of place in the room, and people appeared to be moving in directions different from those they actually followed. Persons walking from right to left disappeared "behind" the patient. There seemed to be a "blanket" on the left side. The symptoms had existed following a sudden feeling as of something "bursting" in the head, right occipital area, followed by collapse; the patient had been under treatment of her physician two months prior to this for a heart and kidney condition; two months elapsed after the attack before the general health improved sufficiently for attention to the ocular condition, at which time I was called in consultation. Patient could see print but "could

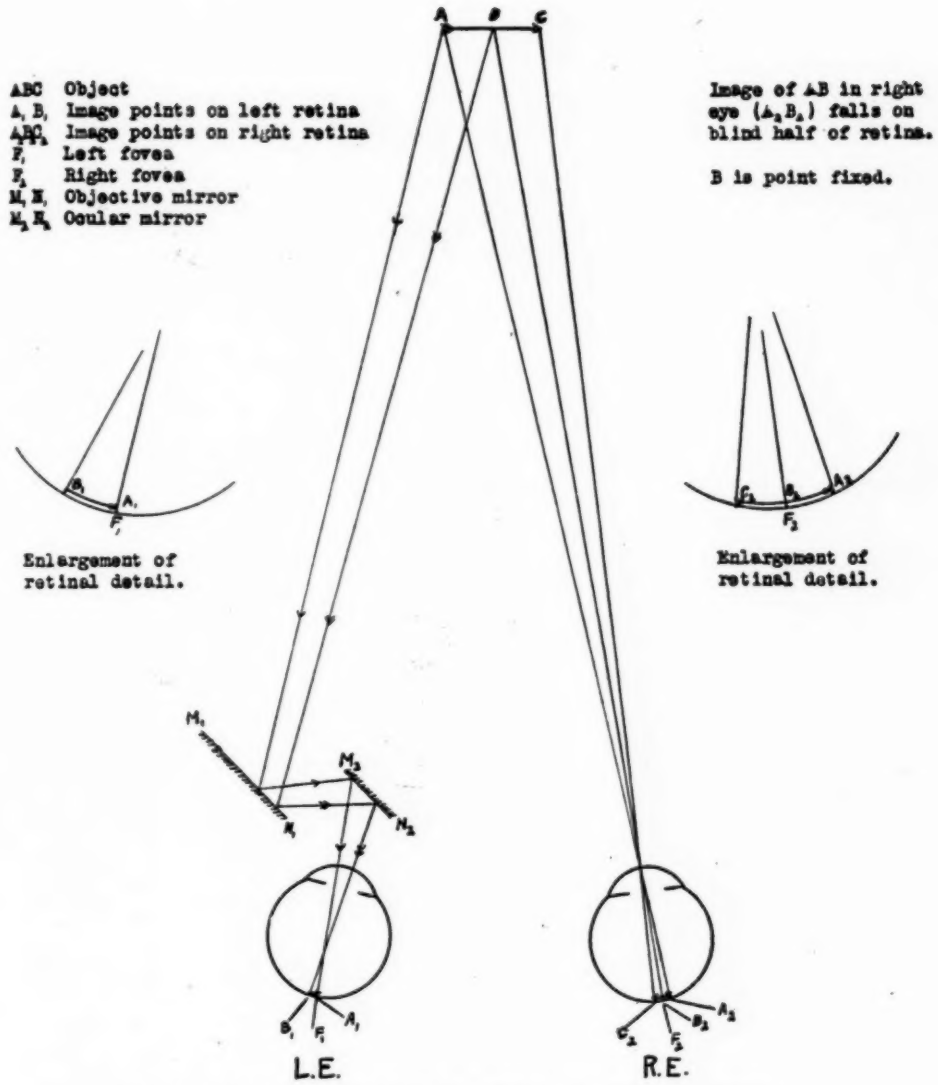
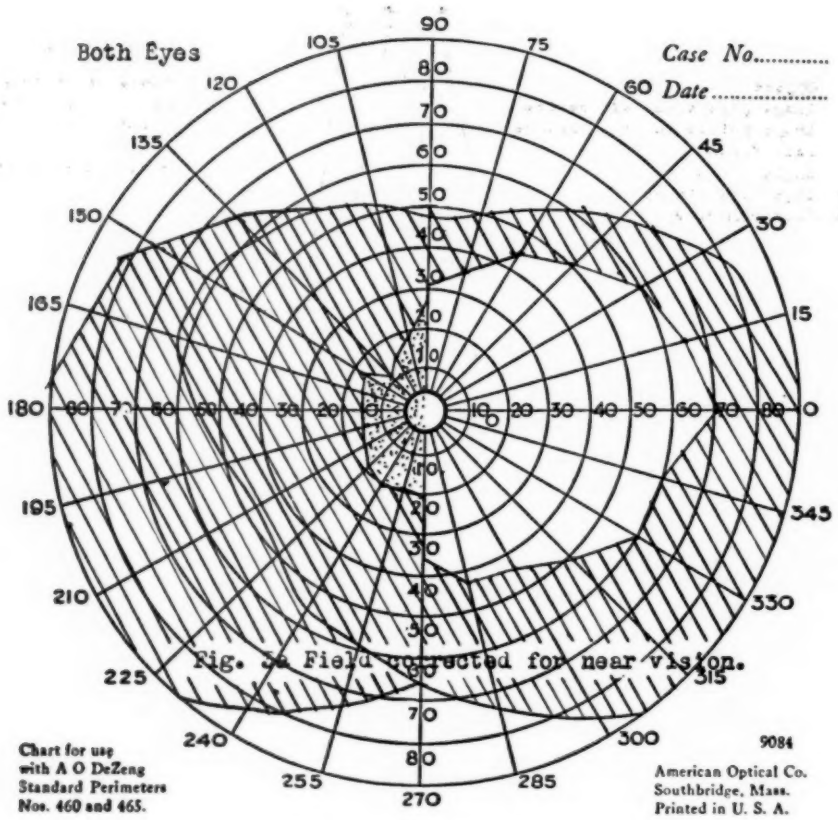

ABC Object
A, B, Image points on left retina
A2B2C2 Image points on right retina
F1 Left fovea
F2 Right fovea
M1 M2 Objective mirror
M3 M4 Ocular mirror
Image of AB in right eye (A2B2) falls on blind half of retina.
B is point fixed.
Enlargement of retinal detail.
Enlargement of retinal detail.
L.E.
R.E.

Fig. 2 Optical System of Hemianopsia Spectacles (Schematic)
Dr Charles E. Jaeckle.

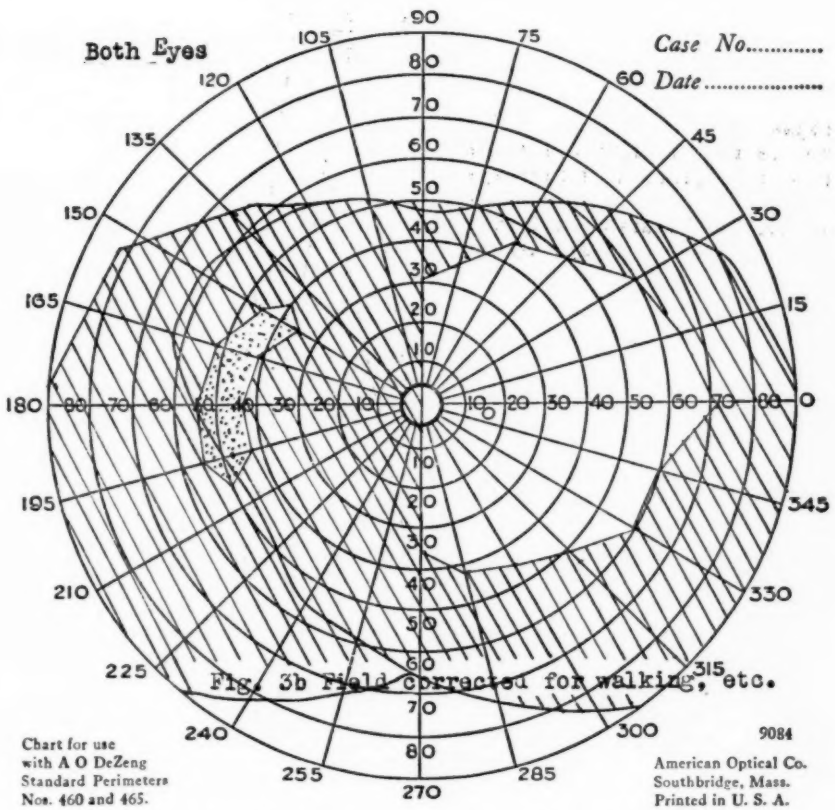
not read it" (she was an avid reader); could not reach for things or put them down on the left side; could "find the knife, but not the fork at the table"; could not play the piano; could knit, but could not crochet; could write, but could not read what she had written. On one occasion when her health had sufficiently improved, she had left the house with-


Both Eyes
Case No.....
Date.....
Fig. 3a Field corrected for near vision.
Chart for use with A O DeZeng Standard Perimeters Nos. 460 and 465.
9084
American Optical Co. Southbridge, Mass. Printed in U. S. A.

Dr Charles E.Jaeckle. Figure 3a.

out the physician's permission; she "could not see people or trees" and ran into them, "could not see automobiles" and dared not step off the curb; she returned to the house frightened. She was bewildered and depressed, largely confined to her chair, deprived of her greatest pleasure and principal activity—reading. The seeming paradoxes involved in the matter of writing and knitting added to her bewilderment and confusion. I mention this detail to convey as vivid an impression as possible of the true effect of her ocular condition on the patient.

Pupils reacted to light, either half of the retina being stimulated. Corrected vision was 10/15 and Jaeger No. 1, either eye or both eyes. Patient's own glasses substantially corrected the ametropia. Perimetry: total left homonymous hemianopsia. (Figs. 1a and b.) (In view of the visual acuity, the macula must have been spared, although this was not indicated in the perimetric examination.)


Both Eyes
Case No.....
Date.....
Fig. 3b Field corrected for walking, etc.
Chart for use with A O DeZeng Standard Perimeters Nos. 460 and 465.
9084
American Optical Co. Southbridge, Mass. Printed in U. S. A.

Dr Charles E.Jaeckle. Figure 3b.

It was decided to attempt correction of the field defect by the use of mirror-spectacles.[1] The spectacles, in this case, were so constructed that before the right eye there is the lens as usual: before the left eye, a mirror is attached to the eyewire temporally, a smaller mirror nasally and the lens mounted between the two mirrors.[2] (Plate I.) The right eye is used for the right half of the field. Light from those objects in the left half of the field is received by the larger mirror, reflected through the lens to the smaller mirror, and then into the eye, impinging upon the left (seeing) half of the retina. (Fig. 2.) The device does not permit the entire left field to be seen, but this is secondary; the small area seen is sufficient to give the patient the necessary guide to movements of the eye to the left and to enable the patient to see obstacles in her path on the left side. (Fig. 3, a and b.) The correct adaptation to surroundings, as indicated by the mirror images, requires

ABC Object
BC Projection of right eye image.
A'B' Normal projection of left eye image.
AB Actual localization of left eye image.

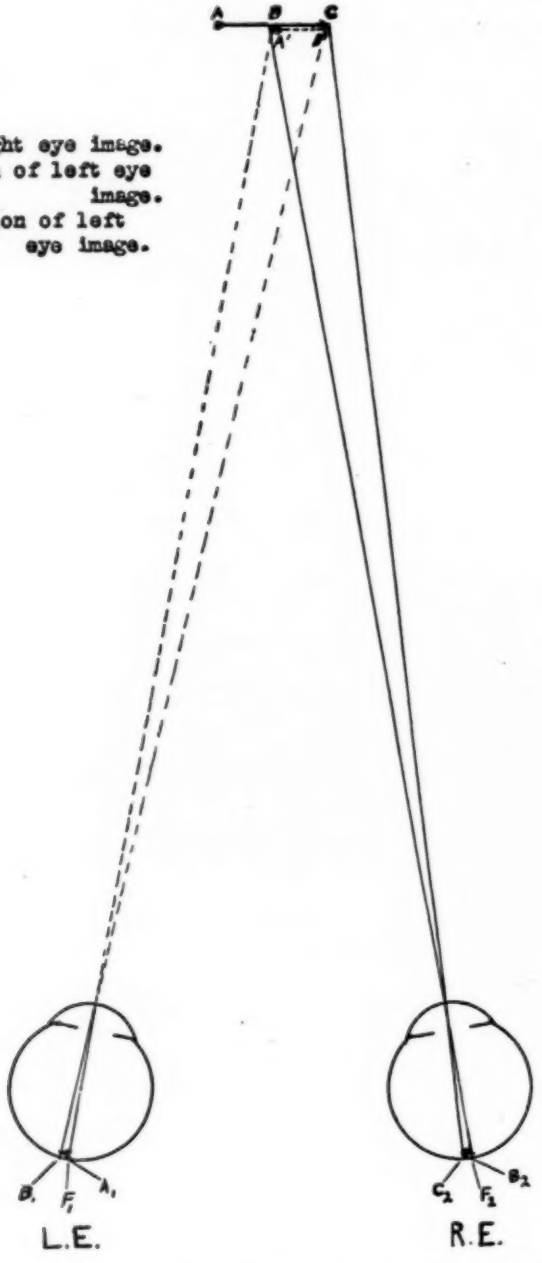


Fig. 4 Projection and Localization with Hemianopsia Spectacles (Schematic)
Dr Charles E. Jaeckle.

that the patient properly localize the objects thus seen. This she does, in spite of the fact that the image in the left eye falls on a part of the retina corresponding to the right field in space and it might be supposed, on the basis of the laws of projection, that the images would therefore be projected into the same locality in space, into which are projected the images of the right eye. (Fig. 4.) This, however, is not the case.

The left lens and mirrors may be rotated about vertical axes. The function of the second mirror is to right the reversed image of the first mirror. The lenses, at first single vision, were changed to bifocals after a few weeks. This is, so far as we know, the first case in which are used bifocal mirror spectacles. The patient experienced no difficulty in getting accustomed to the spectacles from the first day. She read six or seven pages of a book, almost breathlessly, as soon as the glasses had been adjusted. In fact, the patient was so exuberant it was decided not to permit her to keep the glasses lest she become over-confident and attempt too much. When subsequently, we permitted her to walk about with the device before her eyes, she avoided obstacles placed in her path and passed through doorways without difficulty. She goes

Dr Charles E.Jaeckle. Plate II.

Dr Charles E.Jaeckle. Plate III.
Stereoscopic View

out at will when her health permits. All previous activities are now again possible to the patient; in fact, she feels that she has received a new lease on life. The glasses are unusual in appearance, but the patient gives this no thought. (Plates II and III.) She has used them successfully for nearly a year.

Remarks—The vastly greater number of war wounded in Germany results in a larger number of cases of homonymous hemianopsia there than in this country, which no doubt in part accounts for the interest in the condition on the part of German doctors. Nevertheless, there is unquestionably an appreciable number of cases on this continent who would be greatly helped by optical correction of their defects. Their problem is our problem: let us accept it.

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[1]Igersheimer: Gesichtsfeldverbesserung bei Hemianopikern.
Graefes Archiv fur Ophthalmologie, 1919, Bd. 100, S. 357-369.
[2]Made by Carl Zeiss, Jena.

Discussion:

DR. WALTER I. BROWN: The problem of "Homonymous Hemianopsia" was of considerable interest to me from a viewpoint of the nerve pathways involved. The evidence of the proper localization achieved by patients with proper optical correction indicates that the pathways are not as simple or direct as is commonly thought. In the case quoted by Dr. Jaeckle, the patient had almost normal visual acuity in each eye. This, no doubt, was an important factor in permitting proper localization.

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THEORIES OF COLOR VISION

It is estimated that during the last one hundred years more than sixty different theories of color vision have been presented. From this large number of independently conceived hypothesis, however, only three have proven sufficiently valuable to be discussed in the literature of optometry, ophthalmology, psychology, physiology or physics. These three theories were, first, that of Young, which was later added to by Helmholz; second, the Hering theory and, third, the Ladd-Franklin theory. Each of these theories of color vision has much contained within it that is speculative and each has much that can be said in its favor. With each of these theories faults and omissions can be found and for this reason many investigators find themselves dissatisfied with all three. However, each of these theories has many real points of value, these outweighing in each case their existing shortcomings and for this reason the three theories just referred to have withstood the critical investigations of many research workers.

The fact that all colors can be reproduced for practical purposes by mixing suitable quantities of three primary colors suggested to Thomas Young and later on to Helmholz that there are three receiving mechanisms in the eyes which, when stimulated, give raise to primary color sen-

sations of red, green and blue respectively. Each sensation is stimulated by radiation from a considerable range of the spectrum though for each there is a maximum response at a certain wave-length. These receiving mechanisms had, so they theorized, the properties of damped resonators with natural periods corresponding to the wave-length which produces maximum response. The resultant color effect produced by radiation of any wave-length was therefore the mixed sensation due to the partial stimulation of the three primary sensations.

If we had three primary colors, as Young believed, each of which would stimulate one and one only of the primary sensations, these three would then form the natural system of primaries to which all color mixture phenomena could be referred; since, by mixtures of such primaries, it would be possible to reproduce any possible color, both in hue and purity, without introducing negative coefficients.

Unfortunately we cannot find three such colors. If we choose a red of wave-length around 7,000 A.U. or longer, the resulting color is almost entirely a pure red sensation; and if we take a blue from a very short region around 4,460 A.U. we, according to Ives, obtain nearly a pure blue sensation; but there is no color which stimulated the green sensation alone, every green, to the normal eye, stimulating not only green sensation but varying amounts of the other two as well. There is, however, a point in the spectrum, about 5,000 A.U. where the red and blue sensations are equally stimulated. The color here may be regarded as made up of equal stimulations of red, blue and green, that is to say, it is green diluted with a certain amount of complementary red and blue or white. Thus at 5,000 A.U. the spectrum is the same general hue as the pure green sensation would be, were the others absent, but it is less saturated.

The theory of Hering also advances the thought that in the entire retino-cerebral apparatus there are three substances. One of these substances is decomposed by visible radiations of all wave-lengths, although to the greatest extent by the yellow-green radiations, and spontaneously builds itself up in the absence, or relative absence, of radiations of any kind. The other two substances are decomposed at a maximal rate of red and yellow radiations respectively and are recomposed at maximal rates by green and blue radiations respectively. The six psychological primary colors are correlated directly with these six distinctive rates of change occurring in the three substances: White with decomposition of the first substance and black with its recomposition, red and green with corresponding changes in the second substance respectively, and yellow and blue in a similar way with the changes in the third substance. This theory or system of relationships satisfactorily accounts for the manner in which the psychological primaries combine with one another, accounting especially for the "antagonistic" behavior of red and green, and yellow and blue. Negative and complementary after-image effects are also explained, at least qualitatively, and the facts of color mixture are repre-

sented as accurately by this color theory of Hering as by that of the Young-Helmholz theory.

According to the Ladd-Franklin theory of color vision there is only one light-sensitive substance in the retina of the eye. This substance, however, exists in three stages of development or evolution. According to this theory, the first or initial stage is action of light which leads to the excitation of the optic nerve fibers in such a manner as to produce various gradations of achramatic luminosity in the visual sensation ranging from black, which is associated with the absence of excitation, to a white associated with the maximal rate of decomposition. In the second stage of differentiation the substance presents to the action of light two separate portions corresponding, for example, with two different radicles involved in the constitution of its molecules. One of these portions is decomposed at the maximal rate by yellow radiations and the other part similarly by blue radiations, the separate products of these respective decompositions acting upon the optic nerve to produce the colors yellow and blue respectively in the seat of visual consciousness. Simultaneous and equivalent decomposition of the two foregoing portions of the substance, however, reproduces the first or original stage of stimulation of the optic nerve fibers and hence generates a gray in consciousness. The third stage of evolution of the substance involves a differentiation of the yellow-sensitive component into red-sensitive and green-sensitive constituents. When these are acted upon separately they produce a psychologically primary red and green in visual consciousness, but when simultaneously decomposed they yield the original yellow visual value.

It is interesting to note that according to Troland[1] the Young-Helmholz theory of color vision is preferred by physicists because it lays emphasis primarily upon the stimuli to vision, while the Hering theory receives more attention at the hands of psychologists because its fundamental conceptions are derived from introspective analysis. Troland finds also, however, that a number of recent psychological research workers seem to be drifting from the Hering theory to that presented in the Ladd-Franklin hypothesis, since this more recent theory takes into account several sets of fundamental facts that both older theories failed to explain.

C. C. K.

* * * * *

VISUAL FATIGUE CAUSED BY GLARE

Factory workers in certain plants where the lights are unevenly distributed or improperly placed frequently suffer from the effects of glare, resulting from excessive illumination striking the polished surfaces of machines and then being so reflected into the workers' eyes that in time this excessive glare condition causes distress. It is known that when a

[1]Troland, L. T. The Enigma of Color Vision. Amer. Jour. Physio. Optics. Vol. 1, No. 3, page 323, 1920.

bright object is viewed steadily for some time, it becomes appreciably fainter, due to the elements of the retina on which the image falls, becoming fatigued. This fact explains many industrial accidents. It is also known that the effect of fatigue of this kind remains for some time after the stimulus ceases, and if the gaze be transferred to a uniformly illuminated surface, a dark "negative image" of the bright object will be seen, due to the diminished sensitivity of the part of the retina previously occupied by it. This phenomenon may also well play a part in causing industrial accidents where glare and faulty illumination are allowed to play their parts.

Another confusing factor, which may result when glare is present, is the more or less complementary colored negative images. If the object viewed is colored, that visual-color sensation which is most stimulated is also most fatigued, and the negative image is of a color approximately complementary to that of the object. This phenomenon is known as successive contrast. It is not, of course, a true contrast effect. True or simultaneous contrast is observed only when two areas of different brightness adjoin each other. Near this junction the brighter area appears even brighter and the duller area even darker than at a place remote from the junction. If the areas are of slightly different colors the difference is intensified by contrast in the immediate neighborhood of the junction. Contrast effects of this character disappear almost entirely if the areas are separated slightly or divided by a black line.

These visual sensations, due to improper illumination, thus causing reflected glare and fatigue are frequently the cause of symptoms which we as optometrists are called upon to correct. Obviously in these cases the permanent remedy lies not in prescribing absorption lenses, but rather in removing the cause of the visual fatigue by having the plant foreman or manager improve the employees' working condition with reference to illumination.

C. C. K.

BOOK NOTICES

APPLIED REFRACTION WITH SPECIAL REFERENCE TO THE BLUR-POINT TECHNIQUE. Louis Jaques, O.D., and George Crow, O.D. Edited by Lionel Irving Lewis. Published by Harry R. Day, Los Angeles, Calif. Illustrated, 123 pages, $5.00, 1934.

A new study of ocular reactions at the far and near point has just appeared from the pens of Louis Jaques and George Crow, optometrists of Los Angeles. For the past few years much has been said and some short technical material has appeared with reference to "blur-point" and "blur-point-interpretations." During this period much of the really important discussion relative to these findings has naturally centered about these men who have written this book, particularly Jaques, as to him

goes the honor of developing the technics and their interpretations to the point where the findings are of value to us as optometrists.

It is therefore fitting that the book be written as many of the most able refractionists in America have, during the past several years been making use of the diagnostic data derived by making these tests. Not only is there a place in our literature for a book of this kind, but it is doubly welcome, as the work is produced by the authors of the technic itself and therefore gives the exact interpretation they wish to place on the value of these tests.

The book is written from the clinical standpoint. Each portion of the refractive procedure is described in detail. Each step in making the tests is carefully outlined, the findings reviewed, then compared with preceding data, thus making this book one which is easy to read and to follow, and one which enables the reader to readily grasp the procedure in exactly the manner that the author wishes.

Theoretical considerations have been left for the future. The authors largely base the recommendations they make on the data arrived at clinically and while this leaves them open to some criticism, the method has been followed in the healing arts for years and is therefore not new to professional men. This does not of course mean that they have no interest in the theoretical side of the technics they suggest. It means on the other hand that they were primarily interested in presenting certain facts and theories to the profession in the clearest possible manner and in the easiest and most readable way. In this they have succeeded very well indeed. The book is carefully written and nicely put together. For the advanced thinker in optometry it will make a most welcome addition to his library and will enable him to more fully appreciate the efforts of these western optometrists who have added much of value to refractive procedure during the past several years. C. C. K.

* * * * *

MANUAL OF THE DISEASES OF THE EYE FOR STUDENTS AND GENERAL PRACTITIONERS. Charles H. May, M.D., Consulting Ophthalmologist to the Mt. Sinai Hospital, to Bellevue Hospital, to the French Hospital, New York City, and to the Monmouth Memorial Hospital. Fourteenth Edition. Published by William Wood and Company, Mt. Royal and Guilford Ave., Baltimore, Md. Cloth, 496 pages, 376 illustrations, $4.00, 1934.

Diseases of the eye by May was and still is, a standard text book on ocular pathology in most optometric colleges and therefore most optometrists are familiar with some one of the preceding editions of this fine work, now being published in its fourteenth edition. The very fact that it is in its fourteenth edition indicates that the book is of value and also that the author has been able to keep this work well ahead of most

texts of its kind by constant rewriting as progress is made in the specialty. In this edition one finds much new material in the chapters on diagnosis and therapeutic measures and in addition one finds new material in the chapter dealing with the orthoptic development of fusion. Several of the newer technics and instruments are mentioned and the author's handling of the subject indicates that these treatment measures are being given more and more serious study by the leaders of ophthalmological thought as these treatment technics prove themselves to be more and more valuable. This work, in its newest form, is as fine a book as can be had in its field, and is one which should be at hand in every refracting room. C. C. K.

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OCULO-REFRACTIVE CYCLOPEDIA AND DICTIONARY, by Thomas G. Atkinson, M.D. Second Edition. Published by the Professional Press, 5 North Wabash Ave., Chicago, Ill. 384 pages, illustrated, $5.00, 1934.

For the past several months it has been generally known in optometric circles that the Second Edition of Atkinson's Refractive Cyclopedia was nearing completion and we have waited with no little interest for the appearance of this new work. The first edition was published some thirteen years ago. At that time the book was fairly complete but much new material has come into the field since the first edition was brought out, which left that edition in many respects obsolete.

In reviewing the second edition we find that the author has rewritten much of the original material. The work has been entirely reset and the present new volume contains much of value that is either new or that was left out of the first edition. We find, for example, Feinbloom's work with the new Telescopic Cylinder spectacle mentioned in some detail. We find also mention made of the various treatment technics employed by Dr. R. M. Hall, of Cleveland, in treating strabismus. We find a six-page chapter dealing with the psychology of vision and also some twenty pages devoted to the ophthalmometer, these having been written by Dr. Charles Sheard and mentioning the splendid work done in this field by Ryer. Orthoptic treatment technics of various kinds are mentioned in such manner that the optometrist can follow the procedure in a clinical way. The Tait System of Dynamic Skiametry as originated by Dr. Edwin Forbes Tait of the Pennsylvania State College of Optometry is given considerable space, as is the subject of cataract and its treatment. Blur-points and their value as a diagnostic agent in refractive procedure is also gone into, mention being made of the fine work done in this field by Dr. Louis Jaques. These are but a few of the additions that make this work as complete and up to date as it is and the author is to be congratulated in giving the profession as fine a reference book as he has.

This work is moderately priced and a copy belongs on the shelf of

every practicing optometrist. The publishers have spared no expense in making it a volume of value to refractionests and this work, if carefully studied, will do much to broaden the professional outlook of every optometrist. C. C. K.

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DISEASES OF THE EYE, by Sir John Herbert Parsons, Ophthalmic Surgeon; University College Hospital; Royal London (Moorfields) Ophthalmic Hospital, late Ophthalmic Surgeon, Hospital for Sick Children, Great Ormond Street. Published by the Macmillan Company, 60 Fifth Avenue, New York City. 21 colored plates and 343 illustrations, 675 pages, $5.50, 1934.

This is a reprinting of the fifth edition of this standard work on ocular pathology by this famous British authority, Sir John Herbert Parsons. In addition to being a complete work on the Diseases of the Eye the book also deals with ocular anatomy, physiology and refraction in a manner much more thorough than most texts of its kind.

Of particular interest to optometrists is the twenty-six-page section dealing with the ocular manifestations of diseases of the nervous system and the manifestations as they present themselves of other diseases. This chapter is unique inasmuch as it approaches the problem in a manner seldom found and is therefore of value, as the author has prepared this material with care. Incidentally there is room in ophthalmic literature for a text on this subject, as it is one which is neglected by most authors.

While the illustrations are in most cases those used in previous editions, one must again mention their general excellence, as one seldom finds a text of this character as well illustrated as this work of Parsons. The colored plates, too, are splendid. C. C. K.